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Alleviation of Multinutrient Deficiency for Productivity Enhancement of Rain-Fed Soybean and Finger Millet in the Semi-arid Region of India

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*Soil nutrient contents were determined in 802 surface soil samples (0–15 cm deep) collected from farmers' fields that support extensive cultivation of soybean (*Glycine max *L.) and finger millet (*Eleusine coracana *G.), spread across three districts, in the semi-arid regions of Karnataka, India. Following soil analysis, on-farm crop trials were conducted during 2005–2007 to study the crop response to the soil application of nitrogen (N), phosphorus (P), sulfur (S), boron (B), and zinc (Zn) fertilizers. Analyses of soil samples revealed that 4–83% fields were deficient in N, 34–65% in P, 83–93% in extractable S, 53–96% in B, and 34–88% of farmers' fields were deficient in Zn. On-farm trials conducted during the three rainy seasons (2005, 2006, and 2007) significantly (*$P \le 0.05$*) enhanced crop productivity indices such as yields of grain, stover, and total biomass in soybean and finger millet crops. Integrated management of deficient nutrients in finger millet and soybean crops significantly enhanced the grain and straw uptake of N, P, K, S, and Zn.*

Keywords Crop response, nutrient deficiency, nutrient uptake, on-farm trials, productivity indices, soil testing

Introduction

Depletion of soil fertility across the semi-arid tropics (SAT) is a serious global threat to the food security and livelihoods of farmers. Nutrient depletion has been reported especially, in the SAT soils of sub-Saharan Africa (Smaling, Stoorvogel, and Windmeijer 1993; Stoorvogel, Smaling, and Jansen 1993; Harris 1998). Because of the low productivity of the rain-fed lands, it was assumed that the mining of nutrients is much less than under the irrigated systems. Lately, in the Indian SAT, negative balances of nitrogen (N) and phosphorus (P) have been observed in several rain-fed cropping systems on farms (Rego et al. 2003).

Generally, the use of mineral and organic fertilizers in the rain-fed production systems is minimal compared to in irrigated production systems. Most of the fertilizer used in India is confined to irrigation production systems (Katyal 2001). In the rain-fed production

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systems, the deficiency of nutrients are increasing due to small amounts of organic manures used, poor recycling of crop residues, and low use of mineral fertilizers. In the recent years, there has been a decline in the use of single superphosphate and now fertilizer materials such as diammonium phosphate and several grades of complex fertilizers, which are very low in sulfur (S), are being used as the sources for N and P (Tandon 2002). As a consequence, soils are increasingly becoming deficient in S and micronutrients. Use of organic inputs is a viable option to supply nutrients other than those usually supplied by synthetic fertilizers. Nutrients such as S, boron (B), and zinc (Zn) have been reported to be deficient in rain-fed regions of South India (Rego et al. 2007). Fertilization of crops with plant residues and organic inputs is not generally practiced by farmers in the Indian SAT, mainly due to limited availability and alternative uses of the crop residues. Apart from soil moisture shortages often seen in rain-fed zones of India, the increasing frequency of nutrient deficiencies in the SAT soils seems to constrain crop productivity.

In Karnataka, finger millet and soybean are extensively cultivated as a means of livelihood. Edible grains of finger millet is a staple diet for more than a million people, while the finger millet straw is highly valued as feed for livestock. Soybean finds uses in oil production and livestock feed formulations, and stover is fed to cattle. Karnataka is the state in India with second biggest area under rain-fed lands. These rain-fed lands are characterized by erratic rainfall, lack of soil fertility coupled with poverty-stricken population, all combining to create a low per-capita productivity of lands. Under rain-fed agroecosystems, the best results in crop productivity increases can be achieved by adopting a holistic approach in which soil and water conservation measures are implemented along with sound nutrient-management options (Wani et al. 2003). The present study reports the results of studies made in three seasons (2005–2007) to determine the extent of soil fertility depletion in the finger millet- and soybean-growing regions of Karnataka state and the on-farm responses of crops to the application of limiting nutrient combinations. The study also involved recording the on-farm response to the nutrient supplementation in these crops exclusively through the synthetic sources without relying on organic sources.

Materials and Methods

Study Location

The sites selected for the study are located in the hot moist semi-arid agroecological subregion of the Karnataka state, having maximum area under rain-fed agriculture with an erratic rainfall pattern (Figure 1). Mean annual rainfall of the districts ranged from 650 mm (Kolar) to 870 mm (Dharwad), and the study area is characterized by four distinct seasons: hot season (from the middle of February to the end of May), southwestern monsoon (from June to September), northeastern monsoon (October and November), and winter (December to first half of February). On-farm trials were carried out in the southwestern monsoon season.

Sampling and Analysis of Soil and Plant Materials

Briefly, the soils in finger millet (*Elusinae coracona*)–growing regions were mostly dominated by Alfisols and Inceptisols, whereas soybean (*Glycine max*) is extensively cultivated in Vertisols. The sites for finger millet on-farm trials were selected in Kolar and Tumkur districts; soybean-growing sites were chosen in the Dharwad district (Figure 1). The details of soil sample collection procedure and identification of farmers for sampling are provided in an earlier paper (Sahrawat et al. 2008). The composite surface soil samples (0–15 cm

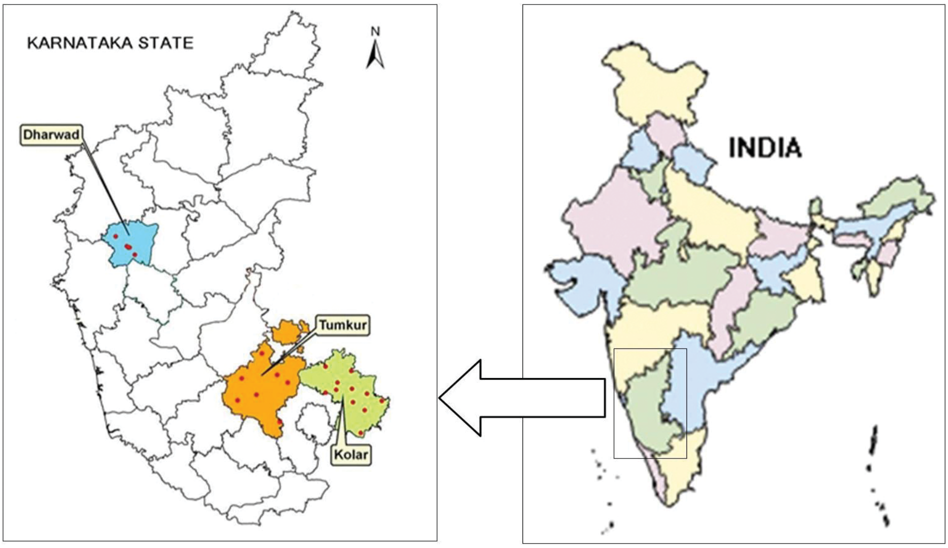

Figure 1. Locations of soil sample collection and on-farm trial sites in Karnataka, India (not to scale) (color figure available online).

deep) thus collected were processed, air dried, and powdered with a wooden hammer to pass through a 2-mm sieve. Prepared samples were analyzed in the Central Analytical Services Laboratory of the ICRISAT, Patancheru, India. For the soil testing of organic C content, the soil samples were finely powdered to pass through a 0.25-mm sieve, and organic carbon (OC) content was estimated by the Walkley–Black method (Nelson and Sommers 1996). Available P was extracted with sodium bicarbonate ($NaHCO_3$) (Olsen and Sommers 1982) and S by extracting with 0.15% calcium chloride (Tabatabai 1996). Neutral normal ammonium acetate–extractable potassium (K) was measured as per the procedure described by Helmke and Sparks (1996). Diethylenetriaminepentaacetic acid (DTPA)–extractable zinc (Zn) was determined according to Lindsay and Norvell (1978); available boron (B) was extracted by hot water (Keren 1996) and estimated using an inductively coupled plasma (ICP)–atomic emission spectroscopy (AES). Soil pH was measured by a glass electrode; electrical conductivity (EC) was determined by an EC meter using soil-to-water ratio of 1:2.

For plant analyses, subsamples of grain and straw were ground in a mill and analyzed for total N, P, K, S, B, and Zn. Total N, P, and K in plant materials were determined by sulfuric acid-selenium digestion. Nitrogen and P in the digests were determined by an autoanalyzer, and K in digests was analyzed by atomic absorption spectrophotometry as explained by Sahrawat, Ravi Kumar, and Murthy (2002). Zinc content of the plant sample was estimated by triacid digestion and atomic absorption spectrophotometry (Sahrawat, Ravi Kumar, and Rao 2002). For the total S and B estimation, plant samples were digested in nitric acid, and an ICP-AES was used for measurements (Mills and Jones 1996).

On-Farm Trials

During the 2005–2007 cropping seasons (June–September) a number of on-farm trials in three districts were conducted in soybean and finger millet crops. There were 16 trials with finger millet in 2005, 17 in 2006, and 27 in 2007 and 6 trials with soybean in the 2005, 7 in 2006, and 11 in 2007. Each farmer for a crop was treated as a replication. In the first season (2005) there were four treatments; the first one was the farmers' inputs (FI). In this treatment, farmers were free to choose the fertilizer materials and their rate of application. Other treatments were different combinations of major and micronutrients, and fertilization was managed by the researchers as follows:

1. FI + NP (60 kg N + 130 kg P_2O_5 ha^{-1}),
2. FI + S BZn (30 kg S + 0.5 kg B + 10 kg Zn ha^{-1}), and
3. FI + NP + SBZn (60 kg N + 130 kg P_2O_5 + 30 kg S + 0.5 kg B and 10 kg Zn ha^{-1}).

These treatments were imposed on 500-m^2 plots, side by side. Farmers' crops, variety, and crop husbandry practices were the same in all treatments. During the 2006 and 2007 seasons, only two treatments were retained, and plot size was increased to 2000 m^2. The treatments tested in 2006 and 2007 were (i) farmers' nutrient input (FI) and (ii) FI + N + P + S + B + Zn.

Nutrients were applied by surface broadcasting before final land preparation after mixing appropriate fertilizers. Nitrogen and P_2O_5 were provided to crops as diammonium phosphate and urea. Sulfur, B, and Zn were supplied through 200 kg gypsum (30 kg S ha^{-1}), 2.5 kg borax (0.5 kg B ha^{-1}), and 50 kg zinc sulfate (10 kg Zn ha^{-1}), and 60 kg N ha^{-1} was applied as basal dose for both crops. An additional 40 kg N ha^{-1} was used for the finger millet, 40 days after planting as a top-dressing.

At the time of harvest of the crops, plant samples were collected from three spots in each treatment. From each spot, areas of about 2 × 1.80 m^2 were harvested in finger millet and 2 × 1.75 m^2 in soybean crop and used for recording yield parameters. Economic parts of the plants were separated from vegetative parts, and fresh weights were taken. Then, a known weight of subsample was brought to the ICRISAT center in Patancheru, Andhra Pradesh (India). The plant samples were dried at 60 °C for 48 h, and dry weights of grain and straw samples were computed.

The data on crop productivity parameters and nutrient uptake were subjected to one-way analysis of variance (ANOVA), and least significant difference (LSD) values between the means were computed at a significance level of 5%. Genstat Discovery software package (Genstat, Hempstead, UK) was used for analysis.

Results and Discussion

Nutrient Status of Farmer's Fields

The soil samples from the farmers' fields of three districts were neutral to alkaline in reaction, with low to medium contents of organic C (Table 1). Soils under the finger millet crop had comparatively less organic C than the soils under soybean. In Karnataka, rain-fed farmers cultivate finger millet for their livelihoods in most marginal soils, and they belong to Alfisol and Inceptisol soil orders according to soil taxonomy. The underlying reason for the high organic C content in soybean-cultivated areas (Dharwad district) could be the fact that legume- based systems are more efficient in enhancing the soil organic C status in the semi-arid tropical soils through the soil addition of leaf litter and root biomass (Wani et al. 2003).

The most striking result of the soil chemical fertility is the indication of widespread deficiency of S, B, and Zn and low levels of N and P in farmers' fields in the semi-arid regions of Karnataka, India. The soil-test results obtained were compared with the sufficiency and deficiency criterions explained by Sahrawat (2002). These results are

Table 1

Soil fertility properties of 802 samples collected from finger millet and soybean farmers' fields in three districts of Karnataka, India

Crops (district)	No. of fields		pH (1:2)	EC (dS m^{-1})	Org C (g kg^{-1})	Olsen P (mg kg^{-1})	Exch. K (mg kg^{-1})	Extractable elements (mg kg^{-1}) S	B	Zn
Finger millet (Kolar)	408	Range	4.5–8.7	0.01–1.8	1.1–12.5	0.2–126	17.0–517	0.5–156	0.04–1.4	0.06–5.5
		Mean	6.7	0.15	3.70	15.3	84	7.3	0.31	0.82
		% deficient[a]			83	34	32	87	90	64
Finger millet (Tumkur)	269	Range	4.8–9.6	0.02–1.7	1.0–10.5	0.20–33	16–402	1.1–60	0.06–0.98	0.14–2.3
		Mean	6.7	0.12	3.70	5.4	80	5.3	0.27	0.49
		% deficient[a]			82	65	32	93	96	88
Soy bean (Dharwad)	135	Range	5.1–8.6	0.04–1.4	4.6–19.9	0.8–54.4	37–563	1.8–118	0.12–2.44	0.28–4.72
		Mean	7.27	0.23	7.86	9.97	145.0	9.05	0.64	1.18
		% deficient			4	44	5	83	53	34

[a]The fertility ratings used for delineation: <5 g kg^{-1} organic carbon, <5 mg kg^{-1} for P, and <50 mg kg^{-1} K are considered low. Critical limits considered are 8–10 mg kg^{-1} for calcium chloride–extractable S, 0.58 mg kg^{-1} for hot water–soluble B, and 0.75 mg kg^{-1} for DTPA-extractable Zn.

indicative of exhaustion of these nutrient reserves through continuous cropping. Previously, it was opined that deficiencies of multinutrients could be expected in irrigated, intensively cropped production systems (Takkar 1996). Low availability of P in the SAT soils may be due to suboptimal levels of phosphate fertilizer used by the farmers.

Crop Productivity and Fertilization

In the soybean crop, compared to FI treatment, the applications of FI + NP, FI + SBZn, and FI + NP + SBZn treatments significantly ($P \leq 0.05$) increased the yields of grain, stover, and total biomass (Table 2). Combined application of N + P + S + B + Zn resulted in an increase of soybean grain yields by 1440 kg ha^{-1} compared to FI, whereas in 2006, an additional grain yield of 1500 kg ha^{-1} was obtained compared to FI treatment. Variations in yield response of soybean during the three crop seasons (FI treatment) might be due to the amount of rainfall and its distribution. The average monthly rainfalls of the crop-growing season (June–September) across the watersheds were 10.2 cm in 2005, 8.6 cm in 2006, and 17.5 cm in 2007. As in the case of soybean, the balanced nutrition of finger millet FI + NP + SBZn significantly ($P \leq 0.05$) improved the grain and total biomass yields during all three seasons (Table 2). Grain and straw productivity of finger millet were significantly greater (60% and 45%) in FI + NP + SBZn treatment than the FI plot in 2005, and the trend was consistent in 2006 and 2007. In crops, FI + SBZn treatment outyielded FI + NP treatment (in 2005), which could be due to enhanced utilization of native as well as farmer-applied nutrients and the nutrient-utilization capacity of the crops. The response

Table 2
Yield response of soybean and finger millet crops under rain-fed conditions in response to fertilization in Karnataka, India (2005–2007)

	Soybean			Finger millet		
Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total biomass (kg ha^{-1})
2005						
Farmer input (FI)	2030	1250	3280	2150	4630	6780
FI + NP	2910	1840	4750	2740	5460	8200
FI + SBZn	3000	1820	4810	2870	5360	8230
FI + NP + SBZn	3470	2150	5620	3350	6650	10000
LSD (0.05)	425	510	690	370	685	1220
2006						
FI	1120	1030	2140	1700	3160	4860
FI + NP + SBZn	2650	2500	5150	2170	4740	6910
LSD (0.05)	660	415	730	580	1250	1400
2007						
FI	2120	1320	3431	2000	6890	8890
FI + NP + SBZn	3120	2130	5247	2950	9120	12070
LSD (0.05)	520	605	1400	690	1630	1755

Table 3
Plant nutrient uptake in grain and straw of rain-fed soybean and finger millet crops in response to the balanced nutrient management in Karnataka, India (2005)

Treatments	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)	S ($g\ ha^{-1}$)	B ($g\ ha^{-1}$)	Zn ($g\ ha^{-1}$)
Uptake by soybean grain						
FI	119.8	9.52	36.7	4.9	51.7	42.9
FI + NP + SBZn	202.4	18.2	65.1	10.8	83.3	90.2
LSD (0.05)	30.4	4.6	18.2	3.5	29.1	14.5
Uptake by soybean stover						
FI	7.6	0.7	11.7	0.4	21.5	3.1
FI + NP + SBZn	13.6	1.9	24.0	0.9	33.8	6.0
LSD (0.05)	4.2	0.8	10.6	0.3	8.5	2.5
Uptake by finger millet grain						
FI	20.2	5.2	11.3	1.8	2.9	35.6
FI + NP + SBZn	30.5	7.5	16.8	2.9	1.8	48.8
LSD (0.05)	8.4	3.5	4.5	0.5	2.1	5.2
Uptake by finger millet straw						
FI	18.8	6.9	60.3	7.9	17.9	139.4
FI + NP + SBZn	44.2	8.6	86.5	13.7	16.6	299.2
LSD (0.05)	23.1	1.4	19.2	3.0	3.5	54.5

seen in the rain-fed soybean and finger millet are of similar magnitude to that reported for several rain-fed crops in Andhra Pradesh, India (Rego et al. 2007).

Nutrient uptake data of soybean clearly revealed that combined application of NP + SBZn significantly increased the uptake of N, P, K, S, B, and Zn by the grain and stover (Table 3). In FI + NP + SBZn treatment, grain uptake was greater by 69% for N, 92% for P, 77% for K, 121% for S, 61% for B, and 110% for Zn over the FI plots. Similarly, FI + NP + SBZn treatment in finger millet enhanced the uptake of N, P, K, S, and Zn nutrients in the grain and stover (Table 3). However, B uptake by finger millet grain and straw was lower by 37% and 12%, respectively, in FI + NP + SBZn treatments compared to FI. High levels of N fertilizer (100 kg ha^{-1}) used in finger millet crop trials probably antagonize uptake of B. In the literature, antagonistic effects of N, P, and S nutrients on B uptake have been recorded (Barker and Pilbeam 2006). However, the differential response of finger millet and soybean crops with respect to B uptake as a consequence of N fertilization needs further investigations. Overall, in soybean and millets, grain and straw compositions of N, P, K, S, and Zn were significantly improved by the application of balanced nutrients.

Conclusions

Evaluation of soil chemical fertility in representative farmers' fields in the Indian state of Karnataka revealed the occurrence of widespread deficiency of plant nutrients such as N, P, S, B, and Zn in the tracts growing soybean and finger millet. Lower per-capita land productivity of soybean and finger millet crops are related to nutrient deficiencies, as these crops responded well to the soil application of these nutrients in terms of enhanced grain, straw, and total biomass productivity. Greater responses observed in field experiments confirm the findings of soil-test results. To realize greater crop productivity in the rain-fed SAT regions of India, it is imperative to correct the deficiencies of plant nutrients. On-farm studies conclude that soybean and finger millet productivity can be significantly enhanced by adopting balanced nutrient management involving combined application of N and P plus S + B + Zn fertilizers. We speculate from the study that the farmers' practice of nutrient management has resulted in depletion of nutrient reserves of S, B, and Zn.

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